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Research Information Needs on U. S.Mangroves: Recommendations to The United States National Oceanic and Atmospheric Administration's Coastal Ocean Program from an Estuarine Habitat Program-Funded Workshop

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Background

In 1988 the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) initiated a Coastal Ocean Program (COP) with management initiatives designed to refocus its activities to support three program elements: **1**) prediction of coastal ocean degradation and pollution; **2**) conservation and management of living marine resources; and **3**) protection of life and property in the coastal region of the United States. The overall COP has a national rather than regional focus. The programs that have evolved under the aegis of the COP are listed below, and are described in more detail by U.S. Department of Commerce (1990):

- Estuarine Habitat Program - designed to evaluate the functional role of estuarine and coastal habitats in supporting living marine resources and to determine the extent of and rates of change of these habitats.

- Nutrient Enhanced Productivity Program - designed to address nutrient overenrichment in coastal waters of the U.S.

- Coastal Fisheries Ecosystem Program - designed to determine how natural environmental variability influences the productivity of coastal and estuarine living marine resources.

- Toxic Chemical Contaminants Program - designed to evaluate the cumulative degradation of coastal organisms, sediment, and water by mixtures of toxic chemicals.

- Physical Impacts Program - designed to address the impacts of episodic and persistent alteration of coastal systems on marine resources.

The COP Estuarine Habitat Program

The Estuarine Habitat Program (EHP) of the COP was established because estuaries and their associated coastal systems are extremely valuable components of the marine environment and are being impacted by man-induced stresses with resulting losses of living marine resources. Two thirds of the Nation's commercial and recreational marine fisheries harvest is estuarine dependent. In fact, estuaries provide food, shelter, migratory pathways, and spawning grounds for over 70 % of the commercial fisheries landed in the United States. These were worth $ 5.5 billion to the Gross National Product in 1986. In addition, recreational fishing generates annual expenditures of over $13.5 billion, while contributing significantly to the quality of life for 17 million anglers (Mager and Thayer 1986, NMFS Operational Guidance 1990).

As human populations increase in the coastal region estuaries are placed under increasing pressure. They are fringed with cities and attendant industries, they serve as transportation corridors, recreational sites, and dumping grounds for society's waste products. Excess nutrients may alter estuarine food webs or lead to conditions that reduce oxygen levels in the water column. Toxic compounds, including halogenated and petroleum-hydrocarbons, occur in fishes and sediments in concentrations warranting concern. Various pathologies in fishes and crustaceans have been linked with waters receiving agricultural drainage or effluent from heavily industrialized areas. Less dramatic but equally insidious are changes in the clarity and volume of water reaching estuarine habitats (Kenworthy *et al.* 1988, 1989 and references cited therein). Silt and particulates from dredging, upstream erosion, or eutrophication reduce the intensity of light reaching estuarine vegetation. The upstream with drawal or addition of large quantities of water in association with domestic, industrial, and/or agricultural uses also may disrupt estuarine habitats and the organisms they support.

The United States House Committee on Merchant Marine and Fisheries recently issued a report entitled "Coastal Waters in Jeopardy: Reversing the Decline and Protecting America's Coastal Resources". The report states:

"The evidence of the decline in the environmental quality of our estuaries and coastal waters is accumulating steadily. The toll of nearly four centuries of human activity becomes more and more clear as our coastal productivity declines, as habitats disappear, and as our monitoring systems reveal other problems... The continuing damage to coastal resources from pollution, development, and natural forces raises serious doubts about the ability of our estuaries, bays, and near coastal waters to survive these stresses. If we fail to act and if current trends continue unabated, what is now a serious, wide spread collection of problems may coalesce into a national crisis by early in the next century".

It is the vegetated wetlands in estuaries (seagrasses, salt marshes and mangroves) that provide the refuge, food resources and nursery areas for a majority of commercially important, estuarine species (e.g., Peters *et al.* 1979, Ferguson *et al.* 1980, Kenworthy *et al.* 1988, Short *et al.* 1989). However, more than half of the original acreage of coastal wetlands of the United States has been lost, and the rate of loss appears to be increasing (Tiner 1984, Kean et al. 1988). Thus, California has lost 87% of its original 3.5 million acres of coastal wetlands. Dramatic declines have also been observed in Florida and in the submerged seagrass beds of Chesapeake Bay. In the southeastern United States, where estuarine-dependence of fisheries is greatest, the loss of coastal wetlands is most pronounced. Louisiana alone is losing 50-60 square miles of wetlands annually. Loss of coastal wetlands results in decreased yields of those species dependent on these habitats. There has been a decline in fish and shellfish harvests of 42% in the southeastern U.S. since 1982; a 66-96% decline in shad, striped bass and river herring in the Chesapeake Bay; a 65% decline in salmon in California; and a 60-80% decline in striped bass in San Francisco Bay, all concomitant with losses of habitat and diversions of freshwater to coastal areas. Thus, the President of the United States has declared a "no net loss" policy for the Nation's wetlands.

NOAA has resource management responsibilities for the nation's living marine resources throughout their range. Accordingly, NOAA is charged with ensuring the continued productivity of the habitats that support these commercially important species.

The EHP, initiated a 1989, focuses special attention on seagrass and saltmarsh-dominated wetlands, and linkages among these and other habitats, because of their importance to the production of living marine resources. Federal and state habitat managers need more quantitative information on the functional mechanisms by which wetlands support living marine resources. Managers need to know the location, extent, and rate of loss or modification of existing wetlands. Finally, managers need to know how to restore and/or create these habitats more effectively. Information on which to base management decisions must be easily available in the form of "...accurate maps depicting where wetlands exist, [and]...information banks containing the results of research on the functioning of wetlands, and on restoration and creation efforts (Kean *et al*., 1988)." Accordingly, the three basic and interrelated objectives of the EHP are:

1. To determine how coastal and estuarine habitats function to support living marine resources. This includes research on factors causing habitat degradation and loss, as well as on methods for habitat restoration.

2. To determine the location and extent of critical habitats and the rate at which these habitats are being changed or lost. This includes satellite, aerial photo-graphic, and surface level surveys to map habitat location and extent, and to determine change through time.

3. To synthesize the new and existing information in the form of mechanistic models of habitat function of use to managers in protecting, conserving, and restoring critical habitats.

Details on the specifics of the EHP research program elements are available from the U.S. Department of Commerce, NOAA Coastal Ocean Program Office, Washington, D.C. 20230.

While the initial effort of the EHP has been on seagrass and salt marsh habitats and their restoration, the EHP has organized workshops to bring scientists and managers together to provide recommendations on future directions of the research program. One such workshop was convened in St. Petersburg, Florida, in 1989, to develop an outline on research and information needs on mangrove habitats in the U.S. The senior author of this paper (GWT) serves as the co-chairman of the Technical Advisory Panel of the Estuarine Habitat Program, and the co-authors of the paper (RRT, SCS, and PFS) served as academic and U.S. Federal workshop coordinators.Others who contributed to the workshop results and their affiliations are listed below:

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The following represents the recommendations from this group of scientists and managers to the NOAA Coastal Ocean Program's Estuarine Habitat Program should the EHP fund an effort directed at mangroves in coastal areas of the United States

Recommendations to the NOAA Coastal Ocean Program's Estuarine Habitat Program for Research Directions on Mangroves

Introduction

Mangroves are a dominant wetland type in the southeastern U.S. They also are found in lesser amounts in other areas of the country and its trust territories. Collectively, four species (red, black, white, and buttonwood mangroves) comprise the "mangrove" forests.

These species singularly or in combinations occupy wide ranges in the coastal zone from regularly flooded tidal regimes to higher elevations that may receive tidal waters only several times per year or during storm events. In spite of their extent, the functional roles of mangroves in supporting primary and secondary productivity in coastal waters, while believed to exist, are poorly understood. Some roles are apparent (e.g., habitat afforded by red mangrove prop roots), but other attributes such as energy flow, linkages to fishery resources, water quality maintenance functions, etc., have been inadequately studied or remain undefined.

It is critical to understand what roles mangroves play in the environment and what products and services (e.g., fishery production, nutrient cycling, storm and wave attenuation) that the different mangrove habitats provide. This need arises because mangroves are under the same pressures as the more widely distributed salt marshes and seagrasses, i.e., direct loss or alteration of mangrove habitat by human development and indirect alteration from varied landward and seaward activities. In the last century many of the estuaries in the southeastern U.S. already have lost more than half of the mangroves that once existed. Mangroves are also a fragile habitat that can be lost to natural events. Examples include the destruction of mangroves in Puerto Rico and the Virgin Islands by Hurricane *Hugo* in 1989 and periodic freeze damage in Florida.

Losses of mangroves continue and efforts at conservation and replacement have met with variable success. Indeed, mangrove restoration projects are widespread, even though functional values of these projects in relation to natural forests are unknown and little follow-up has been accomplished to determine relative success. Current projections from global change research envision global warming and sea level rise that will contribute to great changes in mangrove forest acreage in the Gulf and southeastern U.S. in the next century.

Management and Research Issues

Mangroves occur along the coastlines of all Gulf coast states, Puerto Rico, and the U.S. Virgin Islands; small areas of introduced species are also present in southern California and in Hawaii. The largest regional area, encompassing some 250,000 hectares, occurs in south Florida. Whereas much of the total U.S. mangrove forest area is protected under the jurisdictions of parks, sanctuaries and refuges, this coastal resource is being progressively diminished by a variety of natural and anthropogenic actions. These include such phenomena as: (1) removal for coastal development, (2) deprivation of freshwater from upland watersheds, (3) severe freezes such as occurred in December of 1989, (4) clearing for charcoal production, (5) oil spills and water pollution, (6) competitive exclusion by exotic tree species, (7) illegal cutting or removal, (8) coastal erosion, and (9) mosquito control activities.

As a result of the progressive loss in vegetated area and in the corresponding functional diversity, the life support base for many nearshore fisheries is being increasing placed at risk. This occurs through the loss of physical habitat and the variety of food webs which are based on 1) the enrichment and dispersal of mangrove leaf debris and dissolved organic matter and 2) associated algal and phytoplankton production. This affects both nearshore pelagic and demersal fisheries, as well as a number of high-value benthic-feeding crustacean and mollusc species. Also at risk are the benefits that healthy mangrove vegetation provides through physical shoreline protection and the maintenance of nearshore water quality.

Whereas no direct measures (other than advance planning) can be taken to prevent habitat losses due to increasing climatic extremes and the projected rise in sea level, there are measures that can be taken on the basis of a much improved data and information base. This is based on the recognized fact that protective regulatory policies are best implemented when there is a factual basis. Accordingly, this report identifies a variety of actions and habitat alterations affecting the integrity of the mangrove ecosystem, and offers a priority listing of research initiatives to strengthen the information base. This listing also includes an outline for the development of performance standards for mangrove restoration/creation projects, and a set of evaluation criteria for incorporation in the appropriate research projects.

Research Priorities

I. Food Webs

The prevailing paradigm regarding food webs of mangrove-dominated estuaries is that they are based on the processing of mangrove detritus, in the past focussing almost exclusively on whole leaves and large particulate organic matter (POM). Recent research indicates that the chemically-complex dissolved organic matter (DOM) may have equal ecological significance as POM, particularly at the microbial and meiofaunal levels. POM may serve as a source of rapidly-released soluble organics and ensuing flocculants utilized by microorganisms and small benthic feeders.

Large POM decomposition proceeds at a much slower rate following bacterial nitrogen fixation and fungal alteration of leaf and wood carbon compounds. In salt marsh estuaries, it has been recently demonstrated that relative trophic importance of marsh grasses to filter feeders and higher trophic levels varied both along the length of the estuary and with the presence/abundance of other carbon sources such as algae or seagrasses. An analogous situation may exist in mangrove estuaries.

Objective 1: To determine the contribution of mangroves to estuarine secondary productivity relative to contributions from phytoplankton, benthic micro- and macroalgae, and seagrasses.

Demonstrating the linkage between mangrove primary production and secondary productivity is of high priority. Food web research needs to evaluate: 1) the significance of DOM in sustaining an alternate food web based on heterotrophic organisms and provision of flocculants to benthic feeders, including chemical signature techniques to identify critical phylogenetic groups, environmentally induced shifts in those groups, and experimental feeding/growth studies using lower trophic level invertebrates; 2) the distribution of higher trophic level organisms in various mangrove habitats in relation to gut content analyses; and 3) the use of food web tracers such as stable isotopes.

II. Productivity / Structure

Little effort has been devoted to understanding the relationships between structural and functional attributes of mangrove communities and how these change during stand development. Canopy size, leaf biomass, stand density and biomass, assimilation products and production rates all vary over time and likely affect the quality and quantity of exportable materials. The relative roles of sediment characteristics such as salinity, sulfides, water logging, nutrients and bioturbation as factors influencing mangrove productivity are also poorly understood.

Objective 2: To assess the relationships between mangrove community structure, environmental factors and productivity.

Characterization of the dynamic nature of mangrove productivity is essential in determining the influence of mangroves on the productivity of adjacent coastal habitats. Research is necessary to address those factors controlling the internal structure and function of maturing mangrove stands. In addition, it is recommended that the Coastal Ocean Program's Habitat Mapping component develop protocols that will enable characterization of forest structure, successional status and type.

Mangroves are a subset of the suite of coastal primary producers, but they may directly influence primary and secondary productivity in adjacent waters. The proportional contribution of mangroves to the total primary production of any given estuary is poorly known, as is the latitudinal variation in proportional production in a range of mangrove estuaries. In addition, materials exported from mangroves may stimulate or reduce both primary productivity in adjacent habitats and faunal utilization.

Objective 3: To determine the relative contributions of mangroves, phytoplankton, benthic micro- and macroalgae, and seagrasses to estuarine primary productivity and how mangrove materials affect the productivity of adjacent waters.

Priority research will address: 1) quantification of the rates of primary production of the plant community components within and among estuaries; 2) mechanisms and overall effects of exported mangrove materials, such as nutrient enrichment, stimulation of regeneration, stimulation/ inhibition of aquatic primary productivity by lignins and tannins, increased faunal utilization of mangrove habitats, and how these are influenced by hydrological regimes; and 3) development and testing of a predictive model of the factors that control primary production in mangrove estuaries.

Objective 4: Determine ecological processes associated with recovery and succession of mangrove ecosystems.

The restoration and creation of mangrove habitats depends on fundamental information concerning processes that control the recruitment and establishment of mangrove trees in coastal environments. There is very little understanding of the relative role of gap dynamics and edaphic factors as agents in growth and dynamics of mangroves. What are natural recovery rates of mangrove ecosystems following natural and human induced alterations? How can ecosystem regeneration be enhanced by site improvements such as seeding, removal of woody debris, and changes in elevation? What are the relative impacts of perturbations such as hurricanes, freeze, introduction of exotic species, and toxic materials on the succession of mangroves? The goal of this research objective is to establish construction guidelines for site improvements and initial conditions that will lead to specific successional patterns in restoration of damaged mangrove ecosystems.

Mangroves are particularly vulnerable to damage from hurricanes including defoliation and uprooting. Recovery from hurricane damage in mangroves has been slower than upland forests. Changes in productivity and recovery patterns in different forest types must be documented and studied. Mangroves may be perturbation-dependent systems, yet this does not mean that natural regeneration occurs at rapid rates. What and how can these factors be manipulated to enhance recovery rate of mangroves damaged by hurricanes?

There are preliminary models of mangrove zonation and succession that may have application to the restoration of mangrove habitats. In addition, mapping efforts may contribute to long term understanding of successional patterns of mangrove vegetation.

Objective 5: To determine the significance of hydrology on successional patterns in mangrove habitats. Hydrologic trends should include both long-period climatic oscillations and large scale regional analyses.

Mangroves occupy environments subject to changes in water level which are dependent on balance of tides, upland runoff, river discharge and precipitation. Throughout the development of the stand, structural and functional characteristics are influenced or determined by hydrology. The close coupling of mangroves to other hydrologic units in the landscape suggests that alterations in regional hydrology may induce changes in mangrove vegetation and functional patterns. Mangrove areas in arid environments fluctuate in size as a response to soil salinity. Cyclic patterns in rainfall (periods of prolonged drought) have been cited as causal agents of massive tree mortalities.

III. Habitat Utilization

Past research on the importance of mangrove habitats for fishes and invertebrates has focussed primarily on fringing red mangroves. Whereas the subtidal habitat of mangrove-lined tidal creeks and bays is relatively easy to sample, the densely vegetated intertidal habitats of red, black and white mangroves has prevented all but a few quantitative evaluations of fish and invertebrate usage patterns. This is particularly true of the poorly-researched white mangrove, which appears to have a lower salinity tolerance, a higher tolerance of anoxic sediments, high growth rates, large leaf litter production (fate unknown), and thus a well-defined niche in the mangrove community mosaic. Each habitat type may export DOM that generates chemical cues regulating the presence/absence and abundance of estuarine organisms and thus the predictable spatial and temporal patterns of marine life.

Determining the types and numbers of organisms that exploit these habitats, the functional aspects of habitat usage, and how mangrove carbon is transferred to higher trophic levels is critical. These data will permit analysis and modeling of the linkages between variations in mangrove productivity (natural and human-induced) and variations in faunal abundance, particularly of fishery organisms.

Objective 6: To quantify the direct utilization and ecological functions of mangrove habitats for estuarine fishes and invertebrates over a range of forest types and tidal/hydrological regimes.

Priority research will address: 1) developing quantitative sampling methodology for various forest types and conducting intercalibration of methods; 2) comparing spatial and temporal variation in habitat use by fishes and invertebrates, particularly in relation to critical water levels that permit access; 3) comparing food/feeding ecology and refuge potential in each habitat; and 4) contrasting these patterns and functions among mangrove, emergent marsh, seagrass and non-vegetated habitats.

IV. Nutrient Cycling

Objective 7: Determine the function of mangroves in maintaining water quality of estuarine ecosystems.

Mangroves may influence nutrient dynamics and associated coastal ocean productivity by either removing or contributing primary nutrients to coastal ecosystems. The mass balance approach has been used to determine whether wetlands are either a source or sink of nutrients to the coastal zone. However, there are no published studies of nutrient budgets for mangrove ecosystems. The application of exchange techniques to determine the flux of nutrients in mangrove ecosystems should be investigated. The roles of burial and denitrification as processes associated with the fate of increased levels of nitrogen in the coastal zone are of particular importance.

The role of storms as mechanisms that redistribute nutrients and materials should be assessed. The pulsed nature of exchange should be evaluated as to influence on nutrient and organic matter dynamics of coastal ecosystems.

Objective 8: To determine processes associated with immobilization of nutrients within mangrove ecosystems such as microbial decomposition/enrichment processes and recycling.

The nutritionally important aspect of particulate litter decomposition is nitrogen enrichment, which is postulated to result from bacterial nitrogen fixation coupled with fungal alteration of leaf carbon compounds. Together with retranslocation of nutrients in the forest canopy, these processes provide primary nutrients for the productivity of mangrove ecosystems. These processes may be important relative to exchange in maintaining the fertility of mangrove ecosystems.

V. Restoration / Succession of Damaged Ecosystems

Objective 9: To determine the effectiveness of mangrove restoration/creation/mitigation projects in terms of mangrove community productivity and of faunal utilization patterns.

The effectiveness of restored management habitats in functional equivalency to undisturbed mangrove habitats is poorly understood. The time frame for reaching natural growth and production rates has not been followed in these constructed mangroves, nor have the time courses for development of biogeochemical cycles and natural fish and invertebrate communities. There exist ample sites with documented restoration dates in which to conduct these multidisciplinary studies. Data gathered from these research sites can be used by management agencies in their review of habitat alteration proposals.

Objective 10: To determine effects of natural and human induced perturbations on microbial decomposition/enrichment processes.

Perturbations can alter microbial communities and processes; for example a shift from aerobic to anaerobic surface waters will eliminate fungal communities and promote bacterial anaerobiosis. Therefore it is important to understand how different microbial communities function during decomposition/enrichment and to evaluate various perturbations, such as natural environmental changes, with the additive effects of toxic compounds and their breakdown products.

Objective 11: Assess the significance sea-level variations as factors contributing to successional patterns and loss of mangrove habitats.

Tidal amplitude and the slope of terrain determine the intertidal area available for mangrove establishment. Tidal flooding frequency and duration influence floristic, structural and functional patterns. Changes in tides include diurnal and seasonal water levels, semi-annual and 18.6 year variations, and long-term eustatic rise in mean sea level. The influence of these tidal variations on the structure and function of mangroves need to be determined in different geographical locations.

Objective 12: To assess impacts of anthropogenic contaminants.

Important, expensive and being done by others, but needs to be covered.

VI. Synthesis / Modeling

Objective 13: To develop ecological models of mangrove ecosystems to evaluate the role of mangroves in coastal ecosystems.

Ecological models can be used in conjunction with field and laboratory approaches to obtain a better understanding of mangrove ecosystems. Models can be used to systematically conceptualize ideas about mangroves and thus are a way of hypothesis formulation and testing. Spatial models can address such questions as the fate and effect of exported material and how migratory organisms use mangroves. Also, ecological models of succession and associated ecological processes may assist in design of restoration efforts of damaged mangrove ecosystems.

Objective 14: To produce a synthesis of existing information on ecological processes of mangroves relative to the key management issues associated with these ecosystems.

Scientists and managers need to synthesize existing knowledge of ecological processes of mangroves that address key management issues of mangrove habitats. A document will be prepared to aid in the evaluation of impacts of proposed alterations to mangrove and estuarine habitats.

Prioritization Of Research Objectives

Because the functional linkages between mangrove communities and other communities are poorly understood, we place the highest priority on topics which examine the functional role of mangrove communities in the coastal landscape. The role of mangroves in supporting coastal productivity, Objectives 1, 3, 5, 6, 7, 13, and 14, are particularly important.

Conclusions

This set of objectives addresses management information needs on this habitat type in the southeastern United States, and should provide a template for research proposals elsewhere as well. The Estuarine Habitat Program of NOAA's Coastal Ocean Program intends to use the results of this workshop to guide funding of mangrove research in the future, particularly in terms of their linkages with other estuarine and coastal habitats.

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